

Compatibility and mechanical properties of blends of polystyrene with biodegradable polyesters[☆]

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Abstract

Biodegradable polyesters allow the development of acceptable bio-composites and bio-blends from agricultural-based raw materials without impairing their biodegradability and other useful properties. The tensile properties of binary blends of polystyrene (PS) with the biodegradable polyesters polycaprolactone (PCL), D,L-polylactic acid (PLA), and Eastar Bio Ultra (EBU) were investigated. Blend composition ranging from pure PS to pure biodegradable polyester, in 25% increments, were compounded, injection molded, and used in tensile tests, from which the following tensile properties were calculated: yield stress, yield strain, and modulus. In general, the tensile properties of the PS/biodegradable polyester blends were found to be between the values of the corresponding pure components. Comparison of the yield stress and modulus of the blends with 25% PS showed these properties decreasing in the order: PLA/PS > PCL/PS > EBU/PS, which is the exact opposite of the reported trend in the interfacial tensions of these blends. This implies a correlation between tensile and interfacial properties that is consistent with expectations. However, the data also showed the yield strain and modulus of the pure biodegradable polyesters decreasing in the order: PLA > PCL > EBU, which is identical to the observation on the blends with 25% PS. Thus, the observed trend in the tensile properties could also be due to a contribution from the bulk properties of the biodegradable polyesters.

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Keywords: B. Interface/interphase; B. Mechanical properties; E. Injection moulding; Polymers

1. Introduction

Development of consumer products from renewable agricultural raw materials is currently an area of great interest for researchers in academia, industry, and government [1]. These materials provide inexhaustible and low cost source of raw material for various applications. In addition, these materials can be manufactured, used, and disposed without negatively impacting the environment or the health of people associated with their manufacture, application/use, and disposal. These properties make agricultural products the preferred raw materials over the resource limited petroleum for the manufacture of consumer products.

Nearly all agricultural raw materials have the potential to be used in the manufacture of consumer products,

ranging from automobiles to utensils. Examples of agricultural-based raw materials being pursued for various applications include: vegetable oils [2] (e.g. lubricants); fibers [3] (e.g. composites for automotive); starches [4] (e.g. biodegradable polymers), and cellulose [5] (e.g. bioplastics).

The conversion of agricultural-based raw materials into consumer products, however, is not straight forward. In spite of their abundance, low cost, environmental friendliness, and lack of toxicity, agricultural products lack certain properties that are critical for the manufacture of useful consumer products. For example, agricultural raw materials generally have poor water-resistance, poor oxidative stability, and poor bio-resistance. Thus, successful conversion of agricultural-based raw materials into viable consumer products requires overcoming these and other shortcomings.

One of the methods of improving the properties of agricultural-based raw materials is to blend it with biodegradable polyesters [3,6]. Biodegradable polyesters are high molecular weight polymers that have the useful properties of both synthetic polymers and

[☆] Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by the USDA implies no approval of the product to the exclusion of others that may also be suitable.

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agricultural-based biopolymers. Thus, biodegradable polyesters have the excellent water-resistance properties of synthetic polymers as well as the biocompatibility and biodegradability of agricultural-based raw materials.

Because of these unique properties, biodegradable polyesters are of great interest in the development of products from both synthetic and bio-based raw materials. Biodegradable polyesters allow agricultural-based raw materials to be used in the development of products with improved water-resistance while maintaining its excellent biodegradability. They also allow synthetic materials to be developed into products with improved biocompatibility and biodegradability, without impairing their excellent water-resistance and other properties. As a result, biodegradable polyesters have become critical ingredients in the development of a variety of products including bio-composites [3,7,8], medical devices [9,10], packaging products [11,12].

Successful development of useful products comprising biodegradable polyesters require that the biodegradable polyesters are compatible with the agricultural-based raw materials it is blended with. Currently, biodegradable polyesters are widely investigated as matrix materials in the development of bio-composites with various natural fibers [13,14]. Successful development of useful composites from such efforts is highly dependent on the compatibility of the biodegradable polyesters with the fibers. Various methods (e.g. fiber surface modifications) are being investigated to improve the compatibility of the biodegradable polyester matrix with the agricultural-based fibers.

One of the factors affecting the compatibility of blends of biodegradable polyesters with other materials is interfacial tension [15]. Interfacial tension is a function of the properties of blend components (e.g. chemistry, molecular weight, surface roughness, etc.) and processing parameters (temperature, etc.). The interfacial tension of polymer blends can be measured directly using a variety of methods, or estimated using various empirical and semi-empirical models [16–20]. In our group, we have used the imbedded fiber retraction (IFR) method to investigate the interfacial tensions of blends of biodegradable polyesters with polystyrene [21–25]. The IFR is a dynamic method, which makes it particularly suitable for measuring the interfacial tensions of high viscosity/high molecular weight polymer blends.

The work described here is a follow-up to the interfacial studies mentioned above. In the current study, the mechanical properties of biodegradable polyesters with polystyrene are investigated. The goal is that of evaluating the role of interfacial effects on mechanical properties. Such studies are of great interest in the development of composites and blends from biodegradable polyesters.

Table 1
Polymers used in this work

| Polymer (commercial name) | Abbreviation | Source | T_g (°C) | T_m (°C) |
|-------------------------------------|--------------|---------|------------|------------|
| Polystyrene (Styron 685D) | PS | Dow | 100 | |
| Polycaprolactone (Tone 787) | PCL | Dow | –60 | 60 |
| D,L-Polylactic acid | PLA | Cargil | 57–60 | 170–180 |
| PTAT ^a (Estar Bio Ultra) | EBU | Eastman | –33 | 102–115 |

^a Poly(tetramethylenedipate-co-terephthalate).

2. Experimental

2.1. Materials

Pellets of polystyrene (PS), and the biodegradable polyesters polycaprolactone (PCL), D,L-polylactic acid (PLA), and poly(tetramethylenedipate-co-terephthalate) known under the trade name Eastar Bio Ultra (EBU), were obtained from commercial sources and used as supplied. The source of the polymers and some physical properties are given in Table 1.

2.2. Blends

Binary blends of PS with each of the biodegradable polyesters were prepared by manually mixing the corresponding pellets. The composition of the blends ranged from pure PS to pure biodegradable polyester, at 25% (weight to weight) intervals. The resulting compositions of the binary blends are summarized in Table 2.

2.3. Compounding

The blends were compounded by extrusion into ribbons on a ZSK-30 twin screw extruder (Werner & Pfleiderer, Ramsey, NJ). The ribbons exiting the extruder were fed into a Bronco II mechanical chopper, (Killion, Cedar Grove, NJ), which converted the ribbon into pellets. Some of the blends required longer time to solidify and were cut into pellets manually after the extrusion was completed.

The ZSK-30 has seven heating zones, which can be controlled independently. The blend enters the extruder at Zone 1 and exits at Zone 7. The zone temperatures were adjusted to allow intimate mixing of the components of each

Table 2
Blend compositions, %(w/w)

| PLA/PS | PCL/PS | EBU/PS |
|--------|--------|--------|
| 100/0 | 100/0 | 100/0 |
| 75/25 | 75/25 | 75/25 |
| 50/50 | 50/50 | 50/50 |
| 25/75 | 25/75 | 25/75 |
| 0/100 | 0/100 | 0/100 |

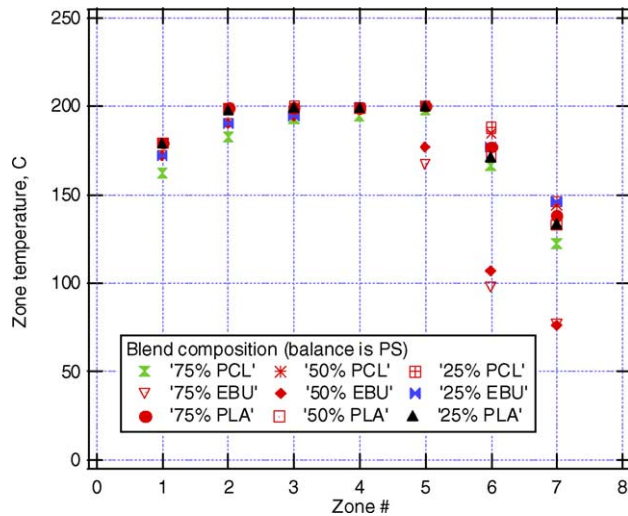


Fig. 1. Zone temperatures used for extrusion of PS/biodegradable polyester blends.

blend. The temperatures of the zones used for compounding the nine blends of polystyrene with the biodegradable polyesters are summarized in Fig. 1. As shown in Fig. 1, all nine blends experienced similar temperature patterns as they moved through the extruder. As the blends progress through the extruder, first the temperature increased (Zones 1 and 2), then it remained more or less constant close to 400 °F (Zones 2–5), and finally decreased (Zones 5–7). The blends experienced the lowest temperature just before exiting the extruder (Zone 7).

2.4. Injection molding

The compounded pellets were used to prepare ASTM D 638 Type I standard tensile bars, by injection molding on a Model ACP 75-D, injection molder (Cincinnati Milacron, Batavia, OH). The nominal width and thickness of the tensile bars were 12.6 and 3.2 mm, respectively. The bars were stored at 73 °F and 50% relative humidity for 7 days prior to tensile test.

2.5. Tensile test

Tensile tests were conducted on Instron Model 4201 Universal Tester (Instron Corp., Canton, MA) equipped with computer control, data acquisition, and data analysis system. Tests were conducted in a climate control room with 50% relative humidity and 73 °F temperature. Tensile tests were conducted at crosshead speed of 50.00 mm/min with data acquisition at a rate of 10 pts/s. A minimum of five specimens per blend were tested and the data averaged to calculate yield stress, yield strain, and elastic modulus.

Young's modulus (referred to as modulus, and symbol E_Y , henceforth) was obtained from the slope of a least square linear fit of the steepest linear region of the displacement vs load data. Yield stress and yield strain

were obtained by the slope threshold method, using a threshold value of 0.301 for the decrease in slope of the data used in modulus calculation.

3. Results and discussion

3.1. Displacement–load profiles of neat polymers

Each of the neat polymers used in this work showed its own distinct displacement–load profiles. These are compared in Fig. 2. PLA displayed the highest ultimate load, which was also its yield load, followed by a break load. On the other extreme is EBU with the lowest ultimate load, which was higher than its yield load due to work-hardening. EBU did not break after 500 mm of displacement, and hence, did not show a break load. The tensile instrument is programmed to automatically stop the test after 500 mm of displacement has been reached. PS showed the second highest ultimate load, which was also its break load, and slightly higher than its yield load. PCL showed similar profile as EBU, which includes a yield load that is lower than the ultimate load, and no break. PCL loads are higher than EBU, but much lower than those of PLA and PS.

3.2. Displacement–load profiles of blends

The effect of increasing the fraction of PS in the blends on the load–displacement profile of binary PS blends with the biodegradable polyesters is illustrated in Fig. 3. Blends of EBU/PS (Fig. 3), and PCL/PS (not shown) displayed the following similar trends: addition of PS resulted in the appearance of break load far below the 500 mm displacement was attained. At 25% PS, the load at break was less than the ultimate load. All loads (yield, ultimate, and break) increased while displacement decreased with increase in

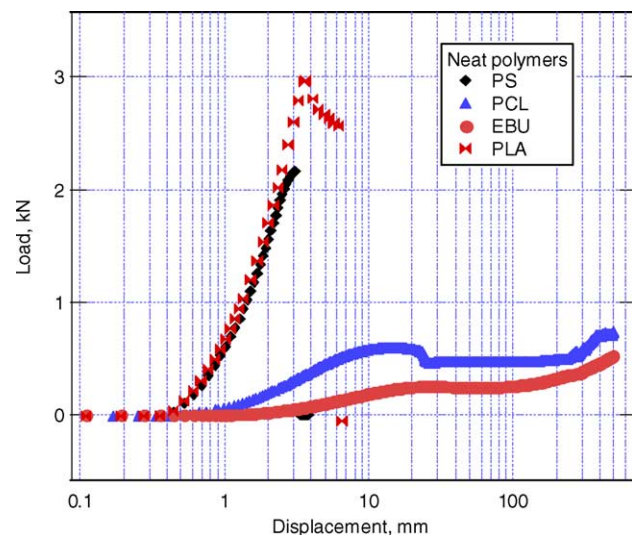


Fig. 2. Displacement–load profile of neat polymers.

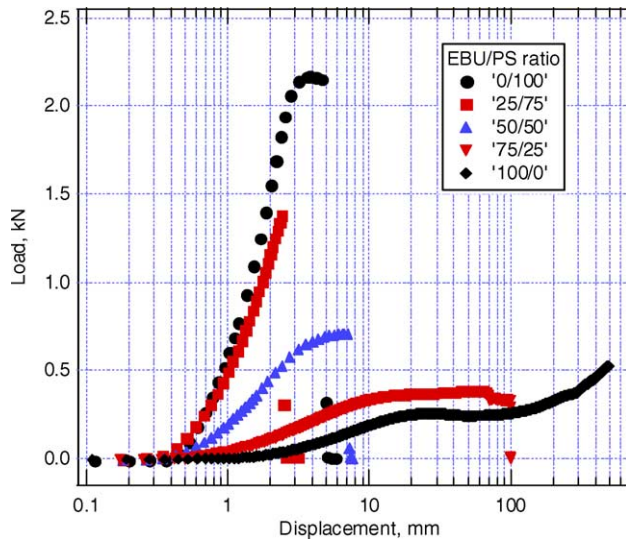


Fig. 3. Displacement–load profile of EBU/PS blends.

fraction of PS in EBU and PCL blends. In EBU blends, the ultimate and yield loads were identical at PS fractions of 50 and 75%. In PCL blends, the ultimate load was greater than the break load at all PS compositions.

Fig. 4 shows the effect of 75% PS on the load–displacement profile of PLA/PS blends. Because of technical difficulties with the injection molding of blends with higher fractions of PLA, only the 25/75 PLA/PS blend was studied in this work. Addition of PS had the opposite effect on PLA blends than that on EBU and PCL blends (please compare Figs. 3 and 4). PS resulted in reduced load and increased displacement of PLA/PS blends, which is the reverse of the observations in EBU/PS and PCL/PS blends.

3.3. Yield stress–strain properties

As mentioned earlier, yield stress and strain values were calculated from the displacement–load data by the slope

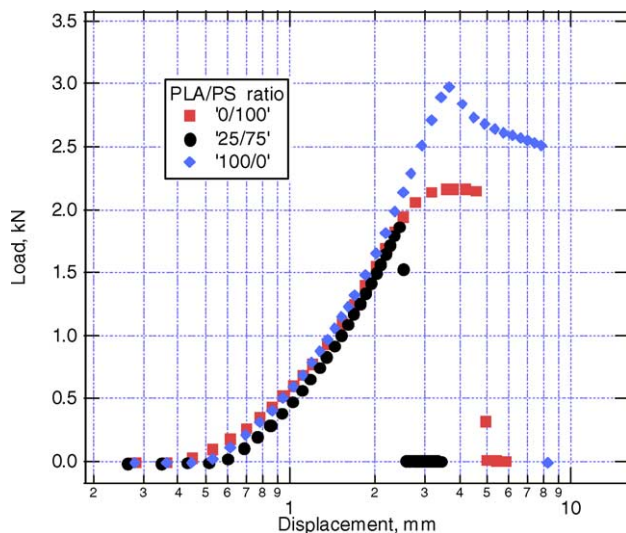


Fig. 4. Displacement–load profile of PLA/PS blends.

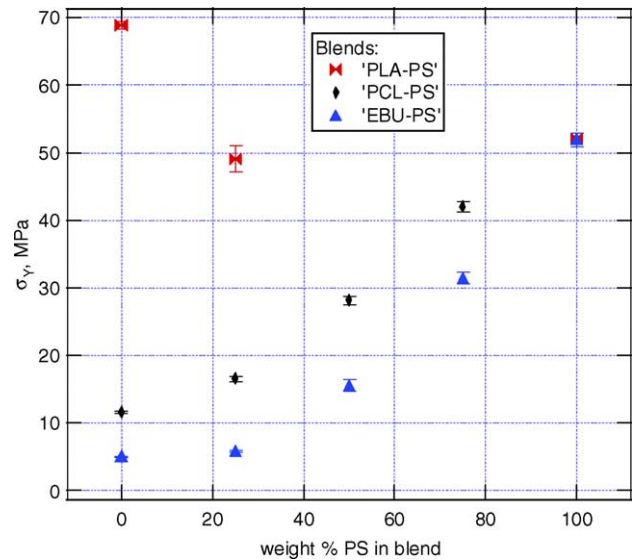


Fig. 5. Yield stress of biodegradable polyester/PS blends as a function of % PS.

threshold method. The effect of increasing the fraction of PS in EBU/PS, PCL/PS, and PLA/PS blends on yield stress and yield strain are summarized in Fig. 5 and Table 3, respectively.

In general, increasing fraction of PS resulted in the increase of the yield stress (Fig. 5), and the decrease of the yield strain (Table 3) of EBU/PS blends. Presence of 25% PS in the EBU/PS blend caused a steep decline in yield strain (Table 3) but a slight increase in yield stress (Fig. 5). The yield strain showed a further steep decline at 50% PS, and remained more or less unchanged at higher PS fractions (Table 3). The yield stress, however, showed a monotonous increase with increase in PS fraction above 25% (Fig. 5).

The general effect of increasing PS fraction on yield strain and yield stress of PCL/PS blends was similar to that described above for EBU/PS blends. As shown in Fig. 5 and Table 3, increasing fraction of PS resulted in increase of yield stress and decrease of yield strain. The yield stress of PCL/PS blends increased more or less proportionately with the increase in the fraction of PS in the blend (Fig. 5). However, the yield strain showed a steep decline up to 50% PS and remained more or less constant above 50% PS fraction in the blend (Table 3).

Table 3
Yield strain of blends of biodegradable polyesters with PS

| %PS | $100 \times \epsilon_y$ | | |
|-----|-------------------------|----------------|----------------|
| | PLA/PS | PCL/PS | EBU/PS |
| 0 | 7.2 ± 0.1 | 11.4 ± 0.2 | 23 ± 0.7 |
| 25 | 5.3 ± 0.5 | 7.5 ± 0.5 | 14.6 ± 1.4 |
| 50 | | 6.4 ± 0.4 | 6.3 ± 0.2 |
| 75 | | 5.7 ± 0.3 | 5.1 ± 0.9 |
| 100 | 6.1 ± 0.6 | 6.1 ± 0.6 | 6.1 ± 0.6 |

As mentioned earlier, because of technical difficulties, we were able to injection mold only the 25/75 PLA/PS blends compounded for this study. Addition of 25% PS to PLA resulted in decrease of both yield stress (Fig. 5) and yield strain (Table 3). This is different from observations on EBU/PS and PCL/PS blends, which showed an increase in yield stress with the addition of PS (Fig. 5).

3.4. Modulus properties of blends

The modulus of all the blends studied in this work, as a function of the fraction of PS in the blend, are compared in Fig. 6. The modulus of pure EBU and PCL were considerably lower than that of pure PS, whereas pure PLA had a higher modulus than pure PS. The modulus values of blends varied between those of pure PS and the corresponding pure biodegradable polyesters.

The modulus of PCL/PS blends showed a linear increase with increase in fraction of PS in the blend. The modulus of PLA decrease due to the incorporation of 25% PS.

Incorporation of 25% PS in EBU caused only a slight increase in the modulus of EBU/PS blend. However, at PS fraction of 25% and higher, the modulus of EBU/PS blend increased linearly with increase in PS fraction in the blend.

3.5. Blend compatibility and tensile properties

Various degrees of compatibility are possible in polymer blends ranging from complete miscibility to phase separation [26]. Compatibility is a function of the interaction of polymer molecules in the blend and can be detected using various methods including mechanical and interfacial measurements.

The mechanical properties of blends vary between those of the neat polymers comprising the blend. In compatible blends, the mechanical properties show a linear relationship

between blend composition and such mechanical properties as σ_Y and E_Y . In general, a negative deviation from the linear relationship is considered an indication of poor compatibility between blend components, whereas a positive deviation is considered an indication of improved compatibility [27].

Examination of Fig. 5 shows a more linear relationship between %PS and σ_Y of PCL/PS blend than that between %PS and the σ_Y of EBU/PCL blend. Examination of Fig. 6 shows similar trend on the effect of %PS on the E_Y of these two blends. This observation might be an indication of better compatibility between PS and PCL than that between PS and EBU. The lone data for the PLA/PS blend showed a negative deviation for σ_Y and a positive deviation for E_Y . More data will be needed to evaluate the compatibility of PLA to PS relative to the other biodegradable polyesters.

3.6. Interfacial tension of blends of PS with biodegradable polyesters

The interfacial tension of blends of PS with biodegradable polyesters was investigated using the IFR method [21–25]. Current methods of interfacial tension measurement can be divided into equilibrium, dynamic, and rheological methods [16,20,28]. The IFR is one of several dynamic methods used for measuring the interfacial tensions of high viscosity blends. Dynamic methods are preferred for measuring the interfacial tension of high viscosity polymer blends because they can be completed in a relatively short period of time, thereby eliminating the risk of polymer degradation.

In the IFR method, interfacial tension is measured from the analysis of the microscopic change in the shape of a fiber of one polymer imbedded in a matrix of a second polymer. The composite is heated to allow the matrix polymer to melt and entomb the fiber. The composite is maintained at the required temperature, which causes the shape of the fiber to change over time. The shape change is driven by interfacial forces but opposed by viscous forces. The image of the fiber is recorded at a suitable time interval, until the fiber is completely transformed into a sphere. From the images, the fiber dimensions are measured and used to calculate the interfacial tension. Over the years, IFR has been used to investigate the interfacial tensions of a number of polymer blends as a function of polymer molecular weight, polymer chemistry (e.g. degree of branching, polarity), temperature, and compatibilizer properties. Details of the IFR method are given elsewhere [21–25].

The interfacial tension of blends of PS with the biodegradable polyesters studied in this work has been investigated using the IFR method [23–25]. In these studies, the interfacial tensions of these blends were measured as a function of temperature. The resulting interfacial tension values were also compared with values predicted using currently available empirical and semi-empirical models.

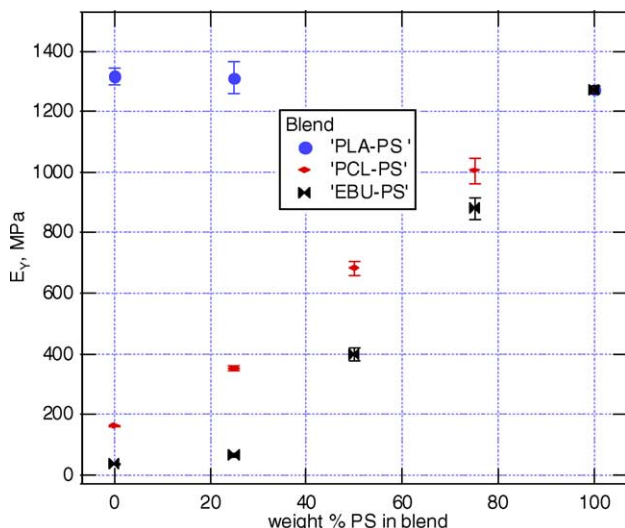


Fig. 6. Young's Modulus of blends of biodegradable polyesters with PS.

Table 4
Comparison of blend γ_{12} with factor C calculated from blend yield stress data

| Blend | DISP phase | B ^a | σ_{yd} (MPa) ^b | σ_{yo} (MPa) ^b | C ^c | γ_{12} (dyn/cm) |
|--------|------------|----------------|----------------------------------|----------------------------------|----------------|------------------------|
| PLA/PS | | | | | | 5.4 ± 1.3^d |
| PCL/PS | PS | 4.91 | 51.9 | 11.6 | 30.2 | 7.6 ± 1.8^e |
| | PCL | 1.91 | 11.6 | 51.9 | 30.2 | |
| EBU/PS | PS | 5.04 | 51.9 | 5.0 | 14.9 | 12.6 ± 2.8^f |
| | EBU | 0.39 | 5.0 | 51.9 | 15.2 | |

^a Obtained from Eqs. (3) and (4). See also Fig. 7.

^b Data from Fig. 5.

^c Calculated using Eqs. (2–4).

^d Ref. [24].

^e Ref. [23].

^f Ref. [25].

The interfacial tensions of these biodegradable polyesters with PS are summarized in Table 4. These interfacial tension data indicate the following trend on the effect of biodegradable polyester chemistry on the interfacial tension of PS/biodegradable polyester blends: EBU/PS > PCL/PS > PLA/PS.

3.7. Quantitative correlation of blend tensile properties with blend interfacial tension

Pukanszky and Tudos [29] have proposed the following empirical equation for relating blend interfacial tension, γ_{12} , with blend tensile properties:

$$C = k/(\gamma_{12})^2 \quad (1)$$

where k is a constant and C is related to stress transfer and is defined as follows:

$$C = (\sigma_{yo}/\sigma_{yd})\exp(B) \quad (2)$$

where σ_{yo} and σ_{yd} are yield stress of the matrix and dispersed phases, respectively; and B is an interaction parameter.

The factor B is proportional to the load carried by the dispersed phase and is obtained from the slope of the following equation:

$$\ln(S_y) = \ln(\sigma_{yo}) + B\Phi_d \quad (3)$$

where

$$S_y = \sigma_y(1 + 2.5\Phi_d)/(1 - \Phi_d) \quad (4)$$

σ_y is the yield stress of blend and Φ_d is the volume fraction of dispersed phase.

The approach of Pukanszky and Tudos [29] has been used to correlate the mechanical and interfacial properties of various polymer blends [29–32]. In all of these studies, the value of C obtained from the analysis of polymer blend tensile data using Eqs. (2)–(4) showed an inverse correlation with blend interfacial tension, as predicted by Eq. (1).

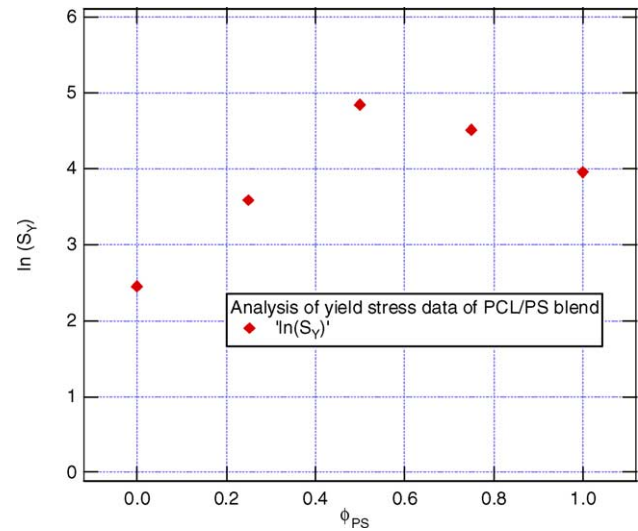


Fig. 7. $\ln(S_y)$ vs Φ_{PS} plot for PCL/PS blends.

The yield stress data from this work shown in Fig. 5 for PCL/PS and EBU/PS blends were analyzed using Eqs. (2)–(4). The PLA/PS blend was excluded from this analysis since there was data for only one blend.

The analysis was done in two steps. First, Eqs. (3) and (4) were used to evaluate B for each blend system. This was done from plots of $\ln(S_y)$ vs Φ_{PS} . Since PS is the dispersed phase at $\Phi_{PS} < 0.5$ and the continuous phase at $\Phi_{PS} > 0.5$, such a plot will result in two straight lines and, hence, two slopes. Thus two B values are obtained for each blend system. A typical plot of $\ln(S_y)$ vs Φ_{PS} is illustrated in Fig. 7.

In the second step, the appropriate B values along with the yield strain values of the dispersed and continuous phases are used to calculate C using Eq. (2). Since there are two sets of these values for each blend, two values of C per blend system are calculated. Table 4 shows the data used in Eq. (2) to calculate C , and the resulting C values for each blend system. Also shown in Table 4 are the reported interfacial tensions [23,25] of the blends. As can be seen in Table 4, the interfacial tensions of PCL/PS and EBU/PS blends display an inverse relation with C , as predicted by Eq. (1).

3.8. Compatibility in blends of biodegradable polyester with PS

The tensile properties of blends of biodegradable polyesters comprising 25% PS are compared in Table 5. This is the only blend composition for which tensile data is available for all three blend systems. Also shown in Table 5 are the corresponding values for the neat PS and neat biodegradable polyesters. The data in Table 5 shows that, for biodegradable polyester blends with 25% PS, (a) the yield stress and modulus decrease in the order PLA/PS > PCL/PS > EBU/PS, (b) the yield strain decrease in the reverse order, i.e. EBU/PS > PCL/PS > PLA/PS, and

Table 5

Comparison of the tensile properties of blends of biodegradable polyesters with 25% PS (and the corresponding pure polymers)

| Property | 75PLA (100PLA) ^a | 75PCL (100PCL) ^a | 75EBU (100EBU) ^a | (100PS) ^a |
|---------------------------|---------------------------------|---------------------------------|--------------------------------|----------------------|
| σ_Y (MPa) | 49.0 \pm 2.0 (68.8 \pm 0.6) | 16.6 \pm 0.4 (11.6 \pm 0.2) | 5.9 \pm 0.1 (5.0 \pm 0.06) | (51.9 \pm 1.0) |
| 100 \times ϵ_Y | 5 \pm 0.5 (7 \pm 0.1) | 8 \pm 0.5 (11 \pm 0.2) | 15 \pm 1.4 (23 \pm 0.7) | (6 \pm 0.6) |
| E_Y (MPa) | 1310 \pm 52 (1316 \pm 29) | 351 \pm 9 (161 \pm 1.2) | 64 \pm 7 (35 \pm 1.3) | (1271 \pm 11) |

^a Values in parenthesis are for 100% polyesters and 100% PS.

(c) the tensile properties of the 25% PS blends follow a similar trend as that of the neat biodegradable polyesters.

The data in Table 5 also shows that, with two exceptions, the values for the tensile properties of the 25% PS blends are within the limits set by the neat PS and the corresponding neat biodegradable polyesters. The exception is PLA with 25% PS, whose yield stress and yield strain values are outside of the limits set by pure PS and pure PLA. Even though this is the only PLA/PS composition studied, the lone data might be an indication of an inferior compatibility of PLA with PS relative to the other biodegradable polyesters.

As shown in Table 4, the interfacial tensions of these blends decrease in the order EBU/PS > PCL/PS > PLA/PS. This trend is opposite of the trend discussed above for the yield stress and modulus values of the blends with 25% PS (Table 5). The relationships between blend interfacial tension and these two blend tensile properties are plotted in Fig. 8. Examination of Fig. 8 indicates that both modulus and yield strength of the blends increase with decrease in interfacial tension. Such result is to be expected if interfacial tension is a major player in the observed tensile properties of these blends.

The data in Fig. 8 implies that PLA is the most compatible with PS, while EBU is the least compatible with PS, and PCL is somewhere in between. Examination of the data presented in this work supports the relative compatibility of PCL and

EBU with PS as presented in Fig. 8. This data includes: (a) the effect of %PS on σ_Y and E_Y (Figs. 5 and 6), (b) the relative values of C computed for these two blends from tensile data (Table 4), and (c) the interfacial tensions obtained from IFR studies of these two blends (Table 4).

The data in Fig. 8 suggesting that PLA is the most compatible of the three biodegradable polyesters to PS are supported by the relatively low interfacial tension of PLA/PS blends obtained from the IFR studies, as well as by the relatively high σ_Y and E_Y values of the PLA/PS blend. However, the tensile data for the 75/25 PLA/PS blend shows a large negative deviation of σ_Y and E_Y . As discussed earlier, such large deviation is an indication of poor compatibility in the blend. This implies that the relatively large σ_Y and E_Y value for this PLA/PS blend might be due to the relatively high σ_Y and E_Y properties of the neat PLA polymer (Table 5). Thus, it appears that tensile and other data on more PLA/PS compositions will be required to conclusively determine the relative compatibility of PLA with PS.

The relationship between interfacial tension and mechanical properties is complex and far from fully understood. For most blends, lower interfacial tension is an indication of improved compatibility, which should lead to improved mechanical properties [26]. There are numerous examples where such correlations between interfacial and mechanical properties have been observed [29]. However, it should also be emphasized that, there are equally numerous examples of observations with no correlations between interfacial and tensile properties of blends [33]. These have been attributed to interfacial effects being overwhelmed by one or more of the numerous other factors (e.g. rheology, test geometry, etc.) affecting mechanical properties.

4. Summary/conclusion

Blends of biodegradable polyesters with synthetic polymers are of considerable interest in the development of biodegradable and biocompatible composites for medical and packaging applications. In this work, the tensile properties of binary blends of polystyrene (PS) with each of three biodegradable polyesters were investigated. The biodegradable polyesters were polycaprolactone (PCL), D,L-poly(lactic acid (PLA), and poly(tetramethyleneadipate-co-terephthalate) known under the trade name Eastar Bio Ultra (EBU). Blend compositions ranging from pure PS to pure biodegradable polyester, in 25% increments, were

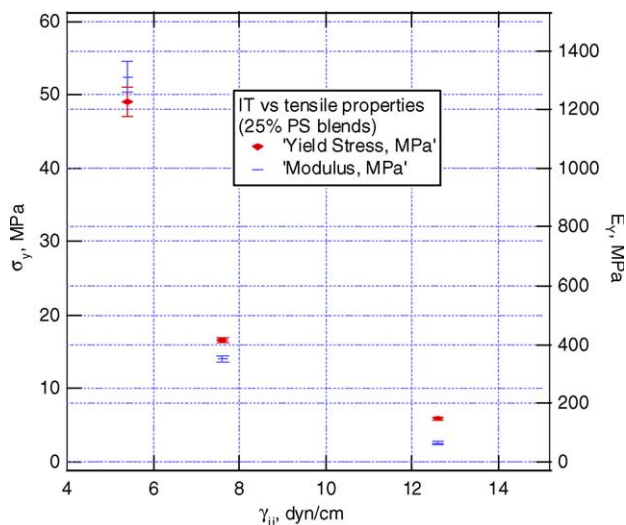


Fig. 8. Interfacial vs tensile properties of blends of biodegradable polyesters with 25% PS.

compounded and injection molded into standard tensile bars. From the displacement–load data of the tensile tests, the following tensile properties were calculated: yield stress, yield strain, and modulus.

In general, the result showed the tensile properties of the PS/biodegradable polyester blends to be between the values of pure PS and the corresponding pure biodegradable polyesters. Comparison of the yield stress and modulus of the biodegradable polyesters with 25% PS showed these properties decreasing in the order: PLA/PS > PCL/PS > EBU/PS. This trend is the exact opposite of the reported trend in the interfacial tensions of these blends, i.e. EBU/PS > PCL/PS > PLA/PS. This implies a correlation between tensile and interfacial properties that is consistent with expectations, i.e. decrease in interfacial tension resulting in increase in yield stress and modulus. However, it should be noted that the data also show the following trend in the yield strain and modulus of the pure biodegradable polyesters: PLA > PCL > EBU, which is identical to the observation on the blends of biodegradable polyesters with 25% PS. Thus, the observed trend in the tensile properties could also be due to a contribution from the bulk properties of the biodegradable polyesters. At this time it is not possible to establish the extent of contribution of these two factors, blend interfacial tension and biodegradable polyesters bulk tensile properties, to the tensile properties of blends of biodegradable polyesters with 25% PS.

Acknowledgements

We would like to thank G. Grose, B. Jasberg, A. Loffredo, A. Thomas, and R. Westhoff for their help with blend extrusion and injection molding; G. Grose, A. Loffredo, and L. Veltman for their help with the tensile measurements.

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